ARMY RESEARCH LABORATORY

Characterization of Silicon Carbide and Commercial Off-the-Shelf Components for High-g Launch and Electromagnetic Applications

Gary L. Katulka
David J. Hepner
Bradford S. Davis
Eric S. Irwin
Melvin B. Ridgley
Kevin T. Kornegay

ARL-TR-2278 AUGUST 2000

Approved for public release; distribution is unlimited.

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5066

ARL-TR-2278 August 2000

Characterization of Silicon Carbide and Commercial Off-the-Shelf Components for High-g Launch and Electromagnetic Applications

Gary L. Katulka
David J. Hepner
Bradford S. Davis
Eric S. Irwin
Melvin B. Ridgley
Weapons and Materials Research Directorate, ARL

Kevin T. Kornegay
Cornell University

Approved for public release; distribution is unlimited.

Abstract

Recent experiments with die-level silicon carbide (SiC) transistors are described. The objective of these experiments was to determine the behavior of SiC field effect transistors (FET) in a high-g environment typical of conventional guns, missiles, or electric launchers. The results of the experiments have shown for the first time that die-level SiC FETs can survive mechanical forces as much as 12,000 times the force of gravity (12,000 g's) without the mechanical support and protection of microelectronics encapsulation materials (e.g., plastic encapsulation material or PEM). A second series of experiments was performed with commercial off-the-shelf (COTS) sensors that rely upon standard sensor technology, including silicon (Si) semiconductors. These experiments provided details of several COTS sensors previously qualified for high-g environements, which are characterized here under harsh electromagnetic interference (EMI) conditions. The sensors tested included an Si optical solar cell, an accelerometer, and a magnetometer. The output response of the sensors was recorded during the EMI event to ascertain the effect of coupled electromagnetic radiation on the sensors.

TABLE OF CONTENTS

INTENTIONALLY LEFT BLANK

LIST OF FIGURES

INTENTIONALLY LEFT BLANK

CHARACTERIZATION OF SILICON CARBIDE AND COMMERCIAL OFF-THE-SHELF (COTS) COMPONENTS FOR HIGH-G LAUNCH AND ELECTROMAGNETIC (EM) APPLICATIONS

1. Introduction

High-g electronic sensors in military munitions as well as high power semiconductor switches in electric weapons stand to benefit greatly from the use of wide band gap semiconductor materials such as silicon carbide (SiC) (Neudeck 1995; Cooper 1997). Electronic sensors for smart munitions could realize great benefits from fabrication designs that include the use of SiC either as active electronic components and sensors (e.g., transistors or microelectro-mechanical systems [MEMS] devices) or as electronic substrates for advanced electronic packaging technologies. One of the main advantages of electronic devices and sensors made from SiC is their ability to tolerate high temperature environments much better than those made from silicon (Si), which is attributable to the higher thermal conductivity (4.9 W/cm-K) and melting temperature (3000° C) of SiC. SiC also has a large Young's modulus (>250 GPa, depending on crystal polytype), which yields improved mechanical strength for devices made from the material. Additionally, SiC electronic devices generally display improved electrical performance compared to Si or gallium arsenide (GaAs) because of its high saturated drift velocity (2×10^7 cm/sec) and wide band gap (3.2 eV), which provide better carrier mobility and high voltage operation.

Previous experimental investigations with SiC prototype devices at the U.S. Army Research Laboratory (ARL) indicated very stable electronic operation during extremely high temperature conditions considered commensurate with environments anticipated for electric weapon technology (Katulka, Kolodzey, & Olowolawafe 1999). Additional benefits of SiC could also be attributed to its potential for high frequency operation, which could allow for electronic device cut-off frequencies at as much as 10 GHz if suitable hetero-structures such as SiC/SiCGe can be alloyed from the material (Katulka et al. 1999). The current experiments detailed here are conducted for the first time with SiC die-level devices in high-g environments typical of gun-launched projectiles. These experiments have been conducted at ARL with SiC field effect transistors (FETs). The experimental results indicate that SiC transistors and the SiC substrate material are capable of withstanding high-g environments without the use of mechanically supporting encapsulant materials.

With regard to present-day sensor technology, the use of commercial off-the-shelf (COTS) components is a critical and economical aspect of munitions and weapons development. During development and diagnostic experiments of military munitions and weapons systems, a significant need exists for projectile

aerodynamic characterization, evaluation of guidance and maneuver systems, and measures of truth for inertial measurement units (IMUs). Much experimentation has been performed with COTS electronics for high-g munition environments. Traditional sensors, signal conditioning, acquisition, and telemetry devices that survive this mechanical loading have had a significant impact on a wide range of military systems. The Hardened Subminiature Telemetry and Sensor System (HSTSS) program is predicated on such a purpose where the focus has predominantly been on high-g survivability (D'Amico, Burke, Faulstich, & Hooper 1996). Similar studies of the effect of electromagnetic interference (EMI) on state-of-the-art components could also lead to extremely reliable built-in diagnostics not only for high g but also for electric launcher technology.

Experiments with several COTS electronic components, which are typically used as conventional ballistic sensors, have been conducted to determine the effects of electromagnetic radiation on system performance. In these experiments, accelerometers, an optical sensor, and a magnetic sensor (magnetometer) are characterized under the influence of an electromagnetic field environment. The peak magnetic field incident to the devices undergoing test is approximately 0.3 Tesla, and although some rail guns can produce 18 to 20 Tesla during launch, the tests described here represent a preliminary evaluation of COTS devices in modest EMI conditions.

2. Experimental Results

2.1 High-G Testing of SiC Field Effect Transistors

A SiC substrate containing an array of complementary metal-oxide-semiconductor (CMOS) FETs, obtained from Cornell University's School of Electrical Engineering, was shock tested in ARL's smart weapons integration laboratory. Specific details about the experimental procedures involved with shock testing for munitions development applications are given in other published literature (Garner 1993). The SiC FET substrate was fabricated so that it contained numerous transistors across the surface of the entire wafer, and again, the specific design features are described in greater detail elsewhere (Lam & Kornegay 1999).

The wafer was mounted onto metallic supporting members with standard semiconductor die-attaching techniques, and it was loaded onto the mechanical shock table at ARL where it was subjected to multiple shock impulses. The test setup is shown in the photograph taken of the shock table and the mounted SiC FET wafer (see Figure 1). Shock testing was performed at increasing levels, beginning at 600 g's and finishing at 18,600 g's where the entire SiC substrate

shattered under the forces exerted by the shock table. The substrate was shocked a total of six times before it finally failed at 18,600 g's. The series resistance of several of the FETs was monitored periodically during the shock testing. This was done by measuring the resistance of the input (FET source and drain) pads relative to the SiC substrate, and capacitance measurements were made on several of the SiC wafer bond pads as well. Any damage, material adhesion failures, or material fracturing would easily have been detected in the characteristic resistance and capacitance of the SiC CMOS transistors.

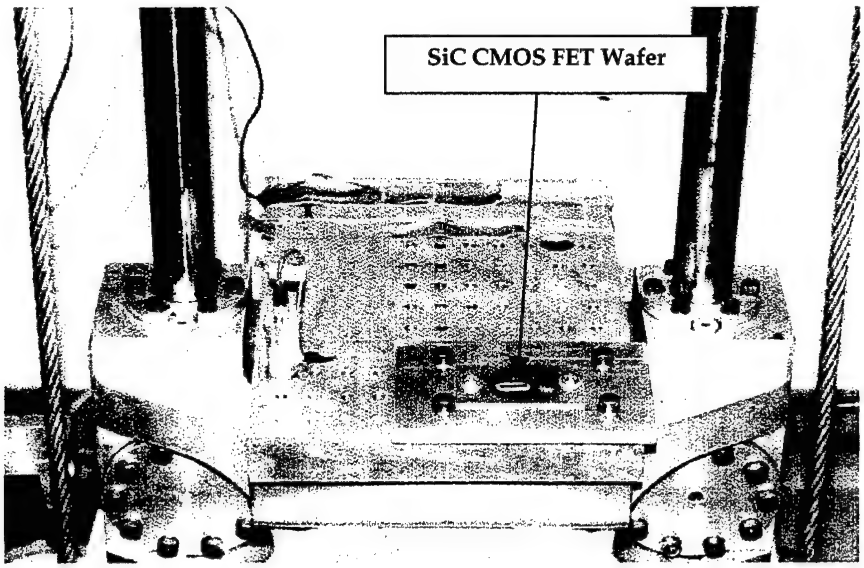

Figure 1. Mechanical Shock Testing Apparatus in ARL's High-g Electronics Laboratory Showing the Mechanical Shock Table With Mounted SiC CMOS FET Substrate.

The resulting measurements are given in the plots of Figure 2 where bond pads 1 through 4 represent the resistance of four different SiC FETs, and pads 5 and 6 represent the capacitance from top-side bond pads to the SiC substrate back side. The results of the electrical measurements indicate insignificant changes in the values measured for the SiC devices and substrate after the occurrence of the shock testing, thus indicating that the SiC devices and substrate successfully survived the mechanical shock loading.

2.2 Testing of COTS Components in a Pulsed EM Environment

The source of electromagnetic radiation in the COTS-EM experiments is a capacitor-based pulsed power supply (see Figure 3) designed by Science Applications International Corporation (SAIC) under contract with the Institute for Advanced Technology (IAT) and delivered to ARL at Aberdeen Proving Ground, Maryland, in 1998. The power supply contains an energy storage capacitor (6 kV maximum), a pulse-shaping inductor, a triggered vacuum switch (TVS), and numerous other high power electrical components. The ballistic

sensors selected for exposure to the EM field environment of the pulsed power supply included two accelerometers (Analog Devices ADXL150 and Endevco 7270A), an optical sensor, and a magnetometer made by Sensor Applications. Accelerometers similar to those tested here have been used recently by the Army for determining the flight characteristics of modified M831 tank munitions at Yuma Proving Ground, Arizona (Muller et al. 1999). The optical sensor was developed at ARL[1] for munitions development. The sensor has been used with MEMS sensors within a NATO[2]-compatible fuze to determine the aerodynamic performance of munitions (Davis & Hepner 1998). The sensor is compact, lightweight, and requires no power. The magnetometer tested in this series of experiments was made by Sensor Applications. The typical application of this device is for determining projectile position, and it is used for providing data about projectile position in relation to the earth's magnetic field.

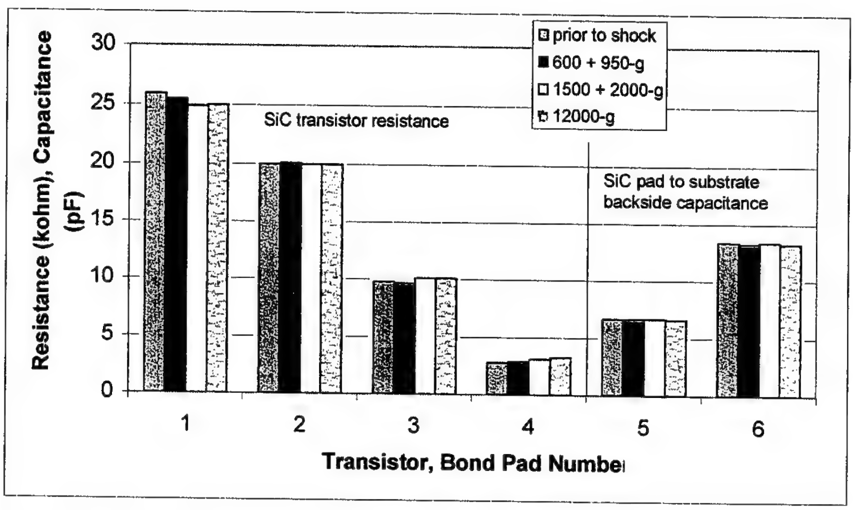

Figure 2. Electrical Measurements of SiC FET Bond Pad to Substrate Back Side Resistance and Substrate Capacitance as a Function of Mechanical Shock Loading.

The responses of the devices exposed to the power supply EM fields are given in Figures 4 through 7. Figures 4 and 5 are the responses of the Analog Devices and Endevco accelerometers, respectively, while Figures 6 and 7 give the waveforms for the optical sensor and magnetometer. In all test cases, each sensor is exposed to the same EM field environment. The behavior of the accelerometers is greatly different, as shown by the output responses in Figures 4 and 5 for the Analog Devices and Endevco accelerometers exposed to EMI radiation.

Note that the two accelerometers represent different device and electronic packaging technologies, which may play a significant role in the different responses to the source EM radiation. For example, the Endevco accelerometer is

[1]Patent no. 5,909,275 issued in June 1999 to D. Hepner and M. Hollis.
[2]North Atlantic Treaty Organization

enclosed in a metal package, which may be responsible for some EMI protection, whereas the Analog Devices accelerometer is enclosed in plastic encapsulation, which will not significantly attenuate electromagnetic radiation. The Analog Devices accelerometer is much more sensitive to the EM pulse in comparison to the Endevco accelerometer. The signal-to-noise (S/N) ratio for the Endevco accelerometer is about a factor of 7 better than that of the Analog Devices accelerometer.

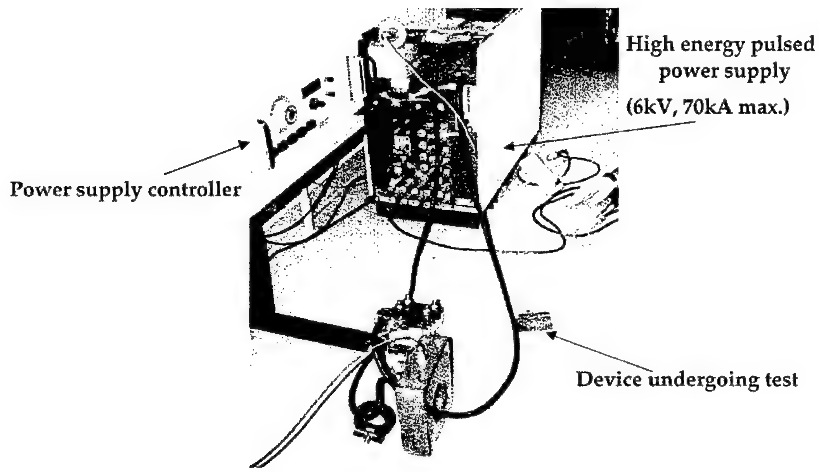

Figure 3. The EM Simulator Testing Apparatus for EMI Qualification and Characteriza-tion of COTS Sensors and Devices in ARL's High-g Electronics Lab. (The power supply is a compact, 6kV, capacitor-based pulsed power system.)

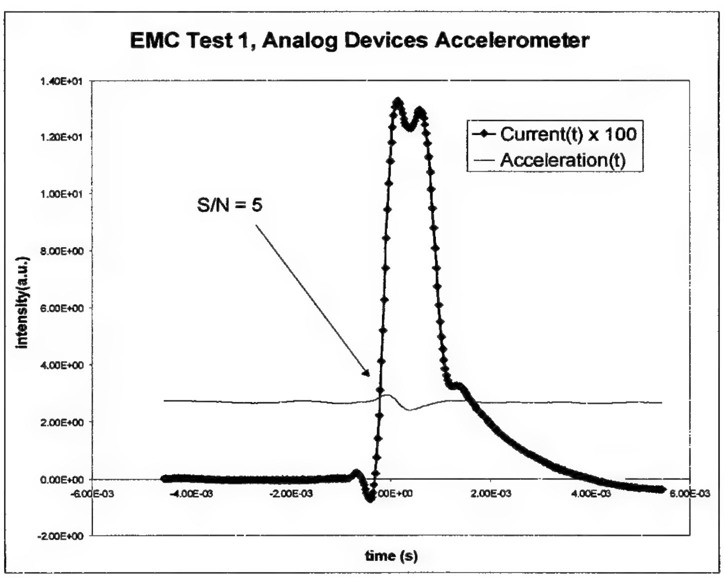

Figure 4. Response of Analog Devices Accelerometer as Exposed to Electro-magnetic Field Environment of a Discharging Pulse-Forming Network. (The acceleration profile is representative of a stationary accelerometer with some noise coupled to the device during the pulse-forming network discharge event.)

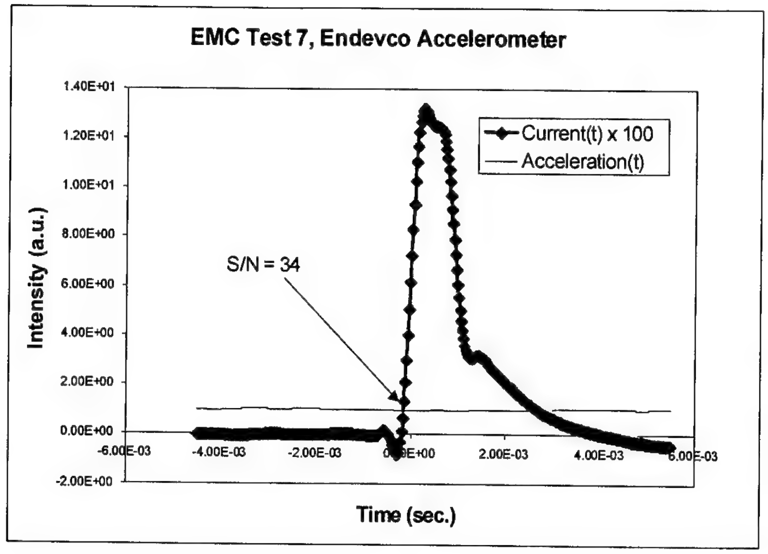

Figure 5. Response of an Endevco Accelerometer as Exposed to the Electromagnetic Field Environment of a Discharging Pulse-Forming Network. (The acceleration profile is representative of a stationary accelerometer with some noise coupled to the device during the pulse-forming network discharge event. The coupled noise is greatly reduced compared to that of the Analog Devices accelerometer for the same external noise source.)

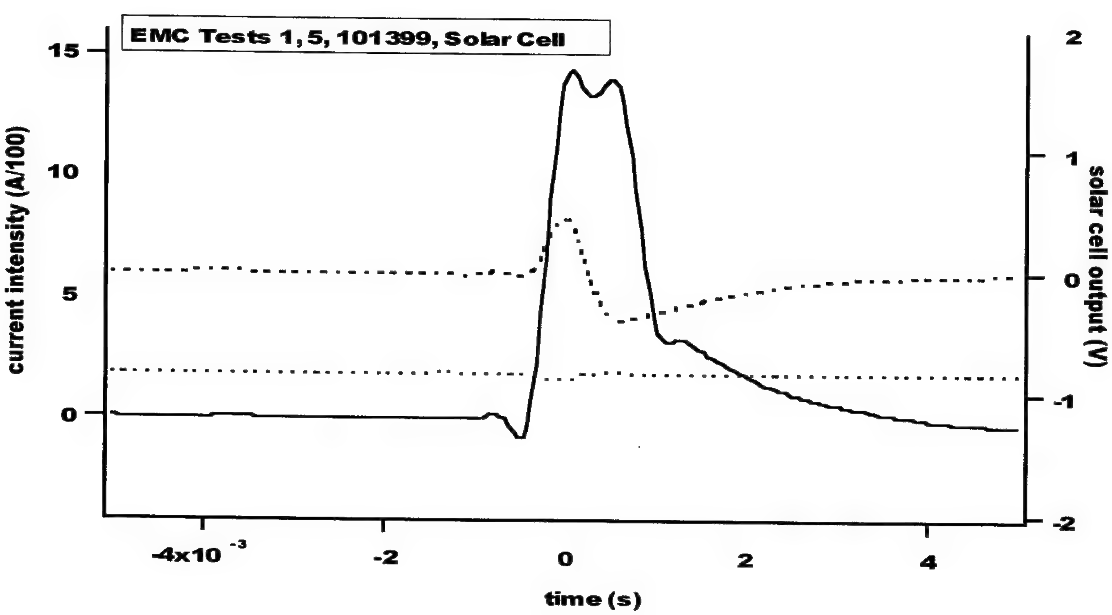

Figure 6. Response of an Optical Solar Cell as Exposed to the Electromagnetic Field Environment of a Discharging Pulse-Forming Network. (The output current waveform from the power supply is shown as the solid red curve. The solar cell output voltage response is given by the dotted curve [red line] for the test with twisted leads, while the standard dual wire configuration is given by the dashed blue curve.)

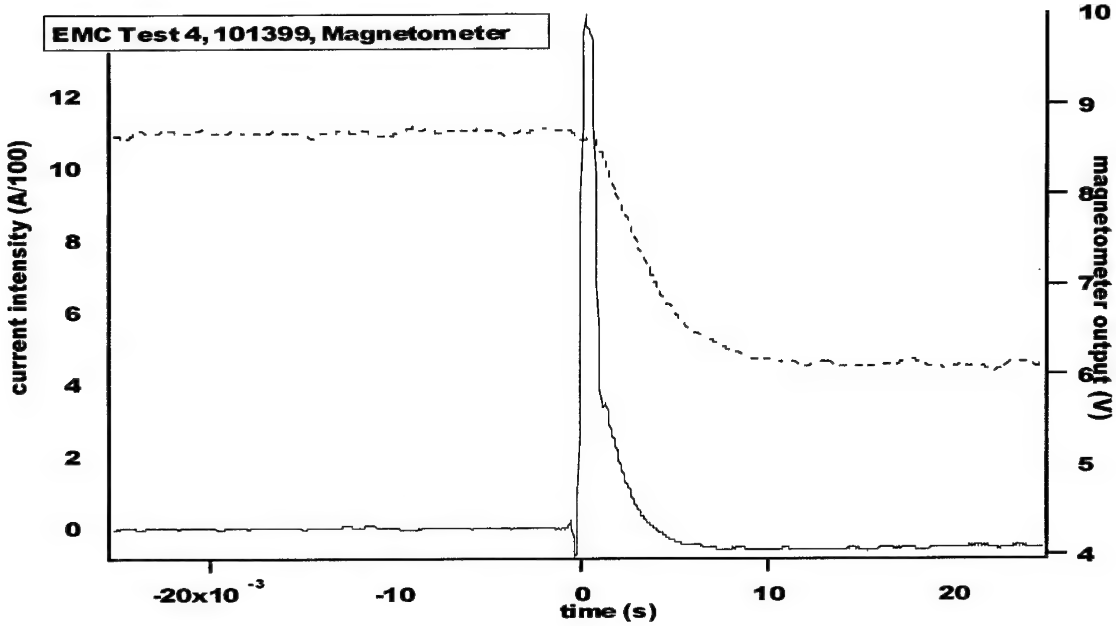

Figure 7. Electrical Response of a Sensor Applications Magnetometer During Exposure to the Electromagnetic Field Environment Generated From the Pulsed Power Supply. (The response of the magnetometer [dotted curve] is very large during the discharge event; however, the device remains electrically biased for more than 20 ms beyond the completion of the discharge.)

The electrical response of the optical sensor as given by Figure 6 indicates that the sensor is quite sensitive to the source radiation when directly exposed to its field as done in the accelerometer tests. A significant electrical disturbance is noted on the optical sensor output waveform as the EM source radiation is activated. The second trace in the figure is the response of the same optical sensor after exposure to the EM source pulse but this time with the use of twisted pair cables. These results indicate that the Si crystal cell can remain electrically isolated and undisturbed with proper engineering and design of the electrical input and output traces of the detector.

Finally, a magnetometer was tested during exposure to the EM radiation source. The output response of the magnetometer during the EM pulse is given in Figure 7, which shows a dramatic shift in the device output to a level equivalent to about one half of the original magnetometer output before the EM pulse.

For the magnetometer test case, it is noted that the device does not recover after the transient EM pulse has ended, but instead, the magnetometer output remains altered for as much as 20 ms beyond the cessation of the pulse. This behavior is believed to be associated with changing the polarization of the magnetometer or inducing electric charge within the magnetometer circuitry. Bench testing conducted with the magnetometer after the EM exposure tests revealed that the magnetometer was properly functioning and that it was not permanently

damaged by the transient EMI, however. While these results indicate sensitivity to EMI, they may also warrant the use of such a device for the experimental characterization and mapping of the EM field characteristics associated with an electric gun. This, of course, would require that it be proved that the magnetometer can provide accurate and reliable measurements during the anticipated EM field conditions.

3. Conclusions

Recent experiments conducted at ARL with bare, SiC die-level FETs have successfully demonstrated the ability of the FETs to survive multiple mechanical shock impulses as great as 12,000 g's, which is the amplitude typically experienced in conventional Army artillery weaponry. The study was conducted jointly with the School of Electrical Engineering, Cornell University, where the SiC transitors were designed and fabricated. It has been shown that the SiC transistors and substrate material remain intact and they can survive multiple shock impulses as great as 12,000 g's without the use of microelectronic encapsulant materials for physical protection. It has also been shown that the physical construction and engineering design of sensors such as COTS accelerometers and optical sensors play a critical role in determining their performance and reliability in electric gun-like EM environments. Additionally, the study of the behavior of a COTS magnetometer operating in an intense EM environment (0.3 Tesla, peak) has indicated that the device is sensitive to EM fields and it does not recover within 20 ms after exposure to the EM field. However, the device was shown to survive the effects from an EM pulse since it was not permanently damaged by the absorbed EM energy.

References

Brown, T.G., B.S. Davis, D.J. Hepner, J.N. Faust, C.R. Myers, P.C. Muller, T.E. Harkins, M.S.L. Hollis, C.L. Miller, and B. Placzankins, "Strap-Down Microelectro-mechanical (MEMS) Sensors for High-G munitions Applications," 10th Electromagnetic Launch Symposium, April 2000.

Cooper, J.A., "Critical Material and Processing issues of SiC Electronic Devices," Material Science and Engineering, Vol. B44, 1997.

D'Amico, W.P., L.W. Burke, R.J. Faulstich, and A. Hooper "The Hardened Subminiature Telemetry and Sensor System Technology Demonstration Phase," ARL-TR-1206. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, October 1996.

Davis, B.S., and D.J. Hepner, "Yawsonde and Micromechanical Systems (MEMS) Accelerometer Data of the M898 Sense and Destroy Armor (SADARM) Projectile During Flight Performance Tests (FPTs) II, III, and IV," ARL-MR-417. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, September 1998.

Garner, J.M., "Shock Test Machine User's Guide," ARL-TN-23. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, September 1993.

Katulka, G.L., J. Kolodzey, and F. Olowolawafe, "Analysis of High Temperature Materials for Application to Electric Weapon Technology," IEEE Transactions on Magnetics, Vol. 35, No 1, January 1999.

Katulka, G.L., C. Guedj, J. Kolodzey, R.G. Wilson, C. Swann, M.W. Tsao, and J. Rabolt, "Electrical and Optical Properties of Ge-Implanted 4H-SiC," Applied Physics Letters, Vol. 74, No. 4, January 1999.

Lam, M., and K.T. Kornegay, "Recent Progress of Submicron CMOS in 6H-SiC for Smart Power Applications," Special Issue of the IEEE Transactions on Electron Devices on Silicon Carbide Electronic Devices, Vol. 46, No. 3, pp. 546-554, March 1999.

Muller, P.C., L.W. Burke, S. Sommerfeldt, B. Lunceford, S. Francomacaro, and J. Lehtonen, "Customizable Multichip Modules for High-G Telemetry Applications," International Telemetry Conference (ITC), November 1999.

Neudeck, P.G., "Progress in SiC Semiconductor Electronics Technology," Journal of Electronic Materials, Vol 24, No. 4, 1995.

INTENTIONALLY LEFT BLANK

NO. OF COPIES	ORGANIZATION
1	ADMINISTRATOR DEFENSE TECH INFO CTR ATTN DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRL CI AI R REC MGMT 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRL CI LL TECH LIB 2800 POWDER MILL RD ADELPHI MD 207830-1197
1	DIRECTOR US ARMY RSCH LABORATORY ATTN AMSRL D D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	OSD ATTN OUSD(A&T)/ODDDR&E(R) ATTN R J TREW THE PENTAGON WASHINGTON DC 20310-0460
1	DPTY CG FOR RDE HQ US ARMY MATERIEL CMD ATTN AMCRD MG CALDWELL 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
2	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN ATTN H FAIR I MCNAB PO BOX 202797 AUSTIN TX 78720-2797
2	DARPA TACTICAL TECH OFC ATTN M FREEMAN S FISH 3701 N FAIRFAX DR ARLINGTON VA 22203-1714

NO. OF COPIES	ORGANIZATION
1	DARPA MICROSYSTEMS TECH OFC ATTN W TANG 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1	NAV SURFACE WARFARE CTR ATTN CODE B07 J PENNELLA 17320 DAHLGREN RD BLDG 1470 RM 1101 DAHLGREN VA 22448-5100
1	US MILITARY ACADEMY MATH SCI CTR OF EXCELLENCE DEPT OF MATH SCI ATTN MAJ R HUBER THAYER HALL WEST POINT NY 10996-1786
1	CDR US ARMY ARDEC ATTN AMSTA AR FSP E D LADD PICATINNY ARSENAL NJ 07806-5000
3	US ARMY TACOM-ARDEC ATTN AMSTA TR D MS 207 M TOURNER J LEWIS MS 208 M SLOMINSKI WARREN MI 48397-5000
4	JHU APL ATTN R BENSON W DEVEREUX H CHARLES D WICKENDEN 1110 JOHNS HOPKINS RD LAUREL MD 20723-6099
1	TACOM/ARDEC ATTN AMSTA AR CCF A M D'ONOFRIO 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	UCLA ATTN W KAISER 56-125B ENGINEERING IV BOX 951594 LOS ANGELES CA 90024-1594
1	ANALOG DEVICES ATTN R MEISENHELDER 804 WOBURN ST MS-422 WILMINGTON MA 01887-3462

NO. OF COPIES	ORGANIZATION
1	MCC ATTN R MIRACKY 3500 W BALCONES CTR DR AUSTIN TX 78759-5398
1	UNIV OF MICHIGAN ATTN C NGUYEN 2406 EECS BLDG 1301 BEAL AVE ANN ARBOR MI 48109-2122
1	RAYTHEON SYSTEMS CO ATTN T SCHIMERT 13588 N CENTRAL EXPWY MS 150 PO BOX 655936 DALLAS TX 76265
2	NSWC/IHDIV ATTN V CARLSON D GARVICK 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
	ABERDEEN PROVING GROUND
2	DIRECTOR US ARMY RSCH LAB ATTN AMSRL CI LP (TECH LIB) BLDG 305 APG AA
2	DIR USARL ATTN AMSRL WM B RINGERS T ROSENBERGER BLDG 4600
1	DIR USARL ATTN AMSRL WM B A W HORST JR BLDG 4600
1	DIR USARL ATTN AMSRL WM B E SCHMIDT BLDG 4600
11	DIR USARL ATTN AMSRL WM BA W D'AMICO T BROWN L BURKE B DAVIS D HEPNER G KATULKA (5 CYS) R MCGEE BLDG 4600
1	DIR USARL ATTN AMSRL WM BC P PLOSTINS BLDG 390

NO. OF COPIES	ORGANIZATION
1	DIR USARL ATTN AMSRL WM BD B FORCH BLDG 4600
2	DIR USARL ATTN AMSRL WM BE G WREN W OBERLE BLDG 390
1	DIR USARL ATTN AMSRL WM BR C SHOEMAKER BLDG 1121
2	DIR USARL ATTN AMSRL WM M J MCCAULEY D VIECHNICKI BLDG 4600
2	DIR USARL ATTN AMSRL WM MB B FINK R LIEB BLDG 4600
2	DIR USARL ATTN AMSRL WM MC M COLE J BEATTY BLDG 4600
1	DIR USARL ATTN AMSRL WM T B BURNS BLDG 309
1	DIR USARL ATTN AMSRL WM TC R COATES BLDG 309
1	DIR USARL ATTN AMSRL WM TD A DIETRICH BLDG 4600
1	DIR USARL ATTN AMSRL WM TE A NIILER BLDG 120
	ABSTRACT ONLY
1	DIRECTOR US ARMY RSCH LAB ATTN AMSRL CI AP TECH PUB BR 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
1	DERA FORT HALSTEAD ATTN COLIN CROMPTON SEVEN OAKS KENT TN14 7BP UK

INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 2000

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Characterization of Silicon Carbide and Commercial Off-the-Shelf Components for High-g Launch and Electromagnetic Applications

5. FUNDING NUMBERS
PR: 1L162618AH80

6. AUTHOR(S)
Katulka, G.L.; Hepner, D.J.; Davis, B.S.; Irwin, E.S.; Ridgley, M.B.(all of ARL); Kornegay, K.T. (Cornell University)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Weapons & Materials Research Directorate
Aberdeen Proving Ground, MD 21010-5066

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Weapons & Materials Research Directorate
Aberdeen Proving Ground, MD 21010-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARL-TR-2278

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Recent experiments with die-level silicon carbide (SiC) transistors are described. The objective of these experiments was to determine the behavior of SiC field effect transistors (FET) in a high-g environment typical of conventional guns, missiles, or electric launchers. The results of the experiments have shown for the first time that die-level SiC FETs can survive mechanical forces as much as 12,000 times the force of gravity (12,000 g's) without the mechanical support and protection of microelectronics encapsulation materials (e.g., plastic encapsulation material or PEM). A second series of experiments was performed with commercial off-the-shelf (COTS) sensors that rely upon standard sensor technology, including silicon (Si) semiconductors. These experiments provided details of several COTS sensors previously qualified for high-g environements, which are characterized here under harsh electromagnetic interference (EMI) conditions. The sensors tested included an Si optical solar cell, an accelerometer, and a magnetometer. The output response of the sensors was recorded during the EMI event to ascertain the effect of coupled electromagnetic radiation on the sensors.

14. SUBJECT TERMS

electric weapons	EM	munitions	silicon carbide
electromagnetics	high g	SiC	wide band gap materials

15. NUMBER OF PAGES
20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102